Dilatant till conditions far upstream on ice stream D

Onset Project Team

RB Alley, S Anandakrishnan, DD Blankenship, PG Braddock, EC King, A Mironov, DL Morse, A Morton, M Nolan, LE Peters, AM Smith, DE Voigt, JP Winberry

ICDS, PASSCAL (R Greschke), UNAVCO (S O'Neel), RPSC

Penn State University

University of Texas, Institute of Geophysics

British Antarctic Survey

NSF

What controls the position of ice streams?

- Conditions at the bed of isD (from seismic reflections).

What controls the position of ice streams?

- Conditions at the bed of isD (from seismic reflections).
- Longitudinal transition from ice-sheet to ice-stream.

What controls the position of ice streams?

- Conditions at the bed of isD (from seismic reflections).
- Longitudinal transition from ice-sheet to ice-stream.
- Lateral boundaries of isD and along-flow of isC (Leo P. poster).

PENNSTATE

What controls the position of ice streams?

- Conditions at the bed of isD (from seismic reflections).
- Longitudinal transition from ice-sheet to ice-stream.
- Lateral boundaries of isD and along-flow of isC (Leo P. poster).
- Bed of isC over “sticky spot” (Paul W. poster).

PENNSTATE

What controls the position of ice streams?

- Conditions at the bed of isD (from seismic reflections).
- Longitudinal transition from ice-sheet to ice-stream.
- Lateral boundaries of isD and along-flow of isC (Leo P. poster).
- Bed of isC over “sticky spot” (Paul W. poster).
- The next frontier: Roughness.

PENNSTATE

Experiment overview

- Seismic experiment to map a change in bed properties along the ice streams.
- Ice stream D: 2 lines
  - ⋆ Near the “driving-stress” onset.
  - ⋆ Upstream of the onset.
- Ice stream C: 3 lines
  - ⋆ Downstream: sticky spot (same as Hermann’s drill line)
  - ⋆ Slightly upstream: in the still-active part
  - ⋆ Far upstream: above the ice stream

PENNSTATE

Geophysically measureable (and measured) properties

- Ice thickness and bed elevation (radar–50MHz, seismics, GPS)
- Deforming till presence (reflection phase) and thickness (seismic reflection)
- Ice velocity (GPS, InSAR)
- Water layer presence (radar) and thickness (seismic reflection)
- Sticky spots (microearthquakes)
- Sedimentary basin thickness and properties (seismic reflection, refraction, gravity)

PENNSTATE

Geophysically measureable (and measured) properties

- Firn density; depth to firn-ice transition (short-offset refraction)
- Accumulation variability (radar–200MHz)

PENNSTATE

Geophysically measureable (and measured) properties

- Crustal thickness and properties (seismic reflection, passive seismic)
- Heat flow (passive seismic)

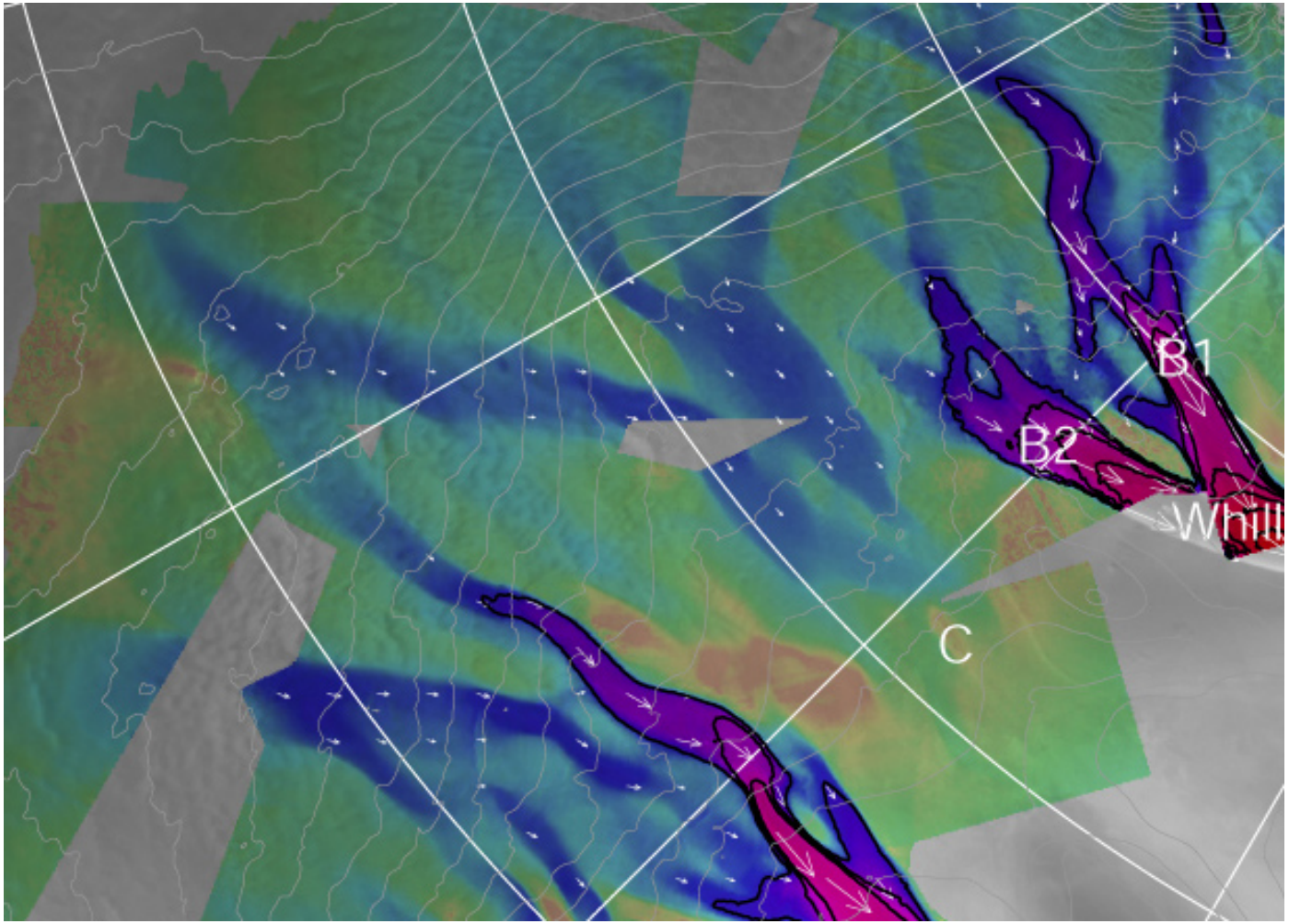
PENNSTATE

Geophysically measureable (and measured) properties

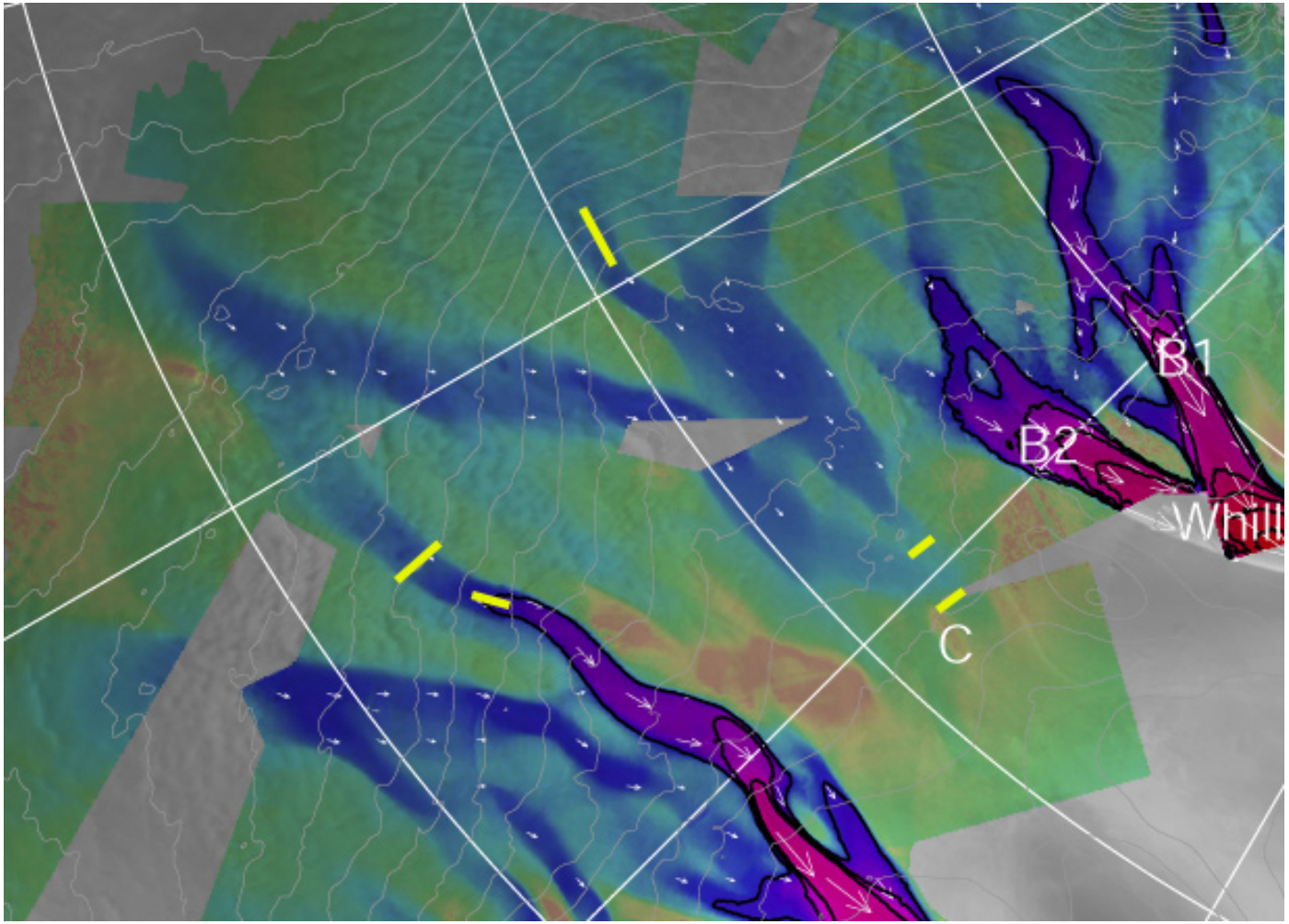
- Crustal thickness and properties (seismic reflection, passive seismic)
- Heat flow (passive seismic)
- Inner core anisotropy (passive seismic)

PENNSTATE

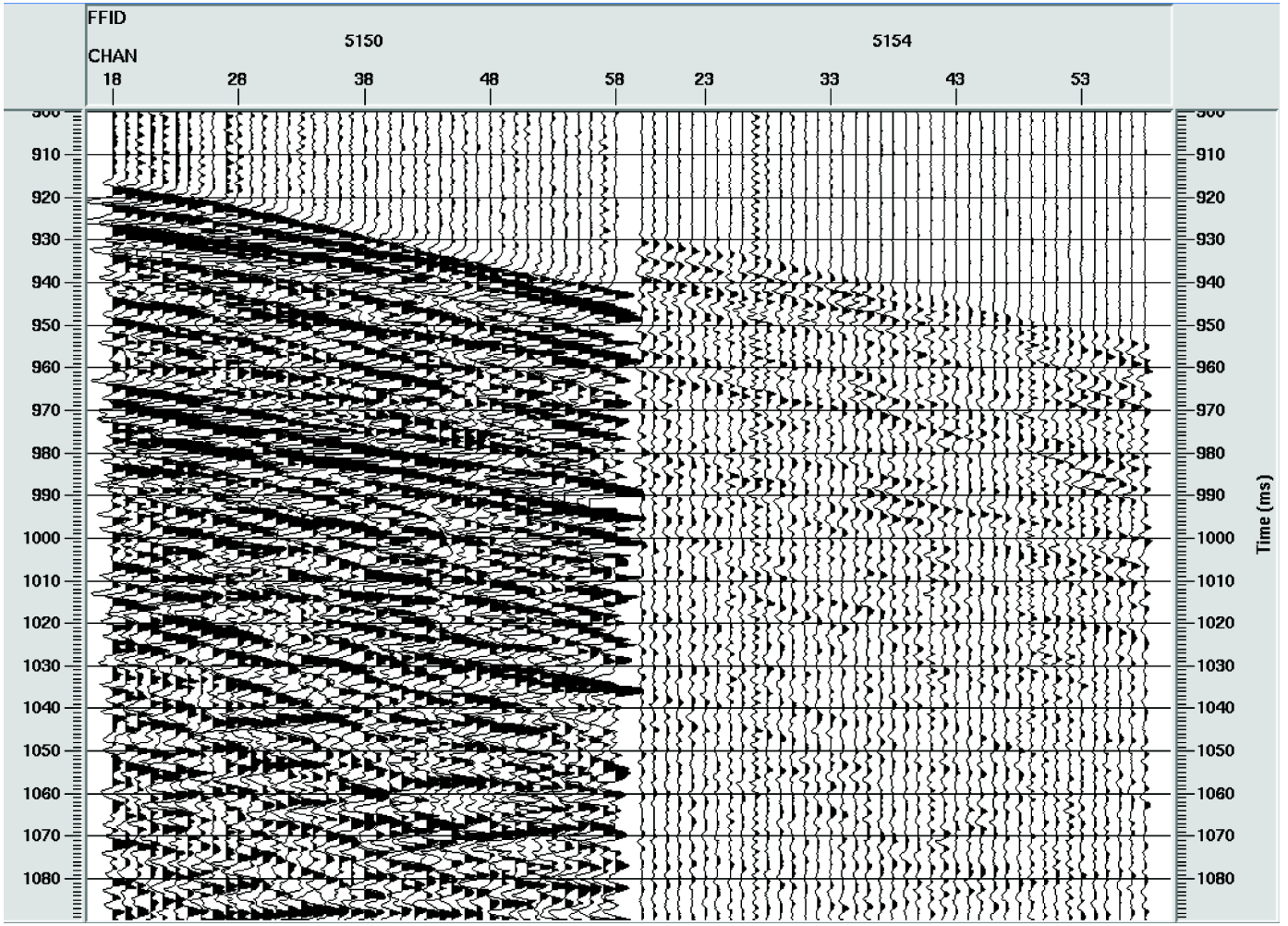
Field project area



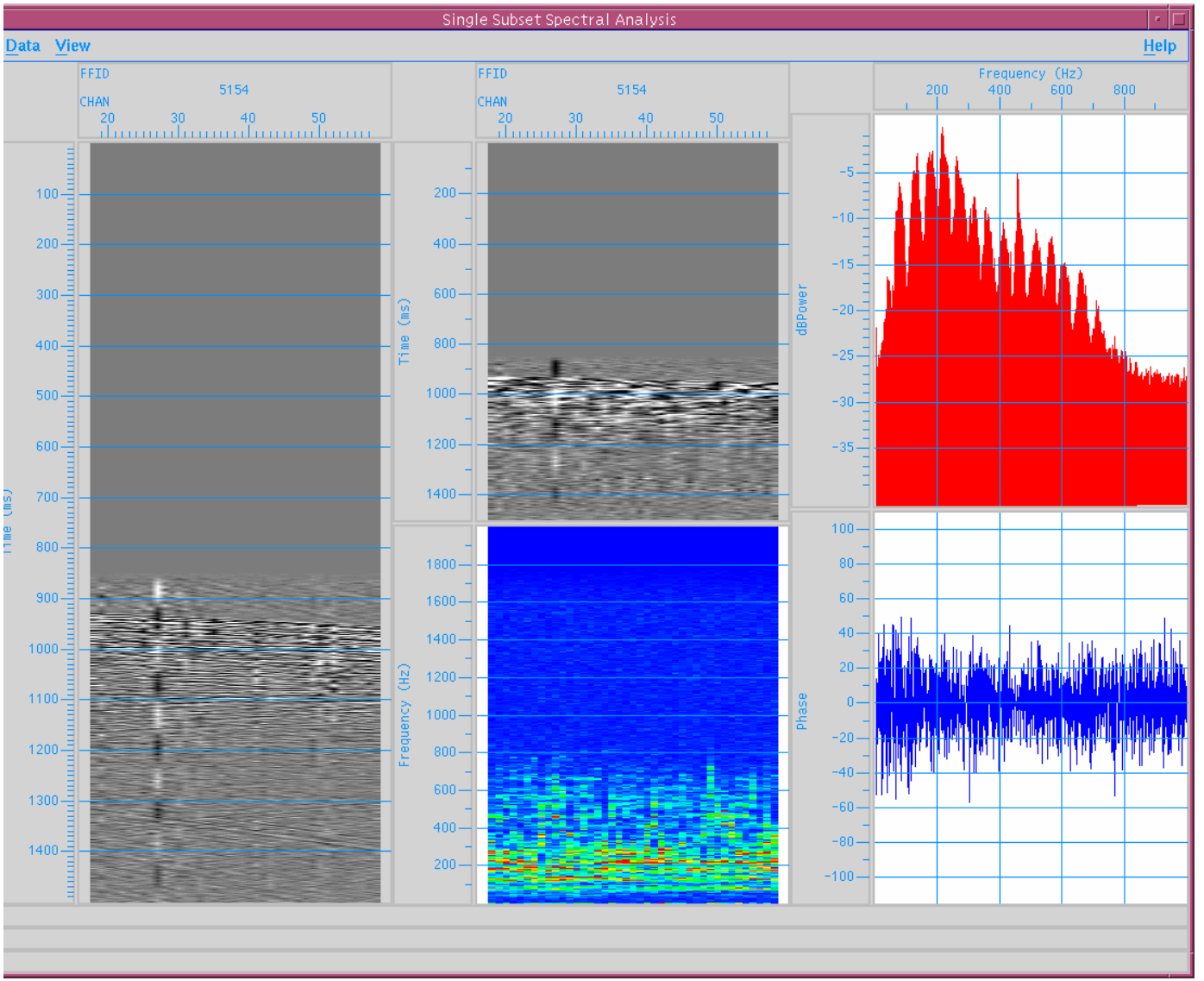
Field project area



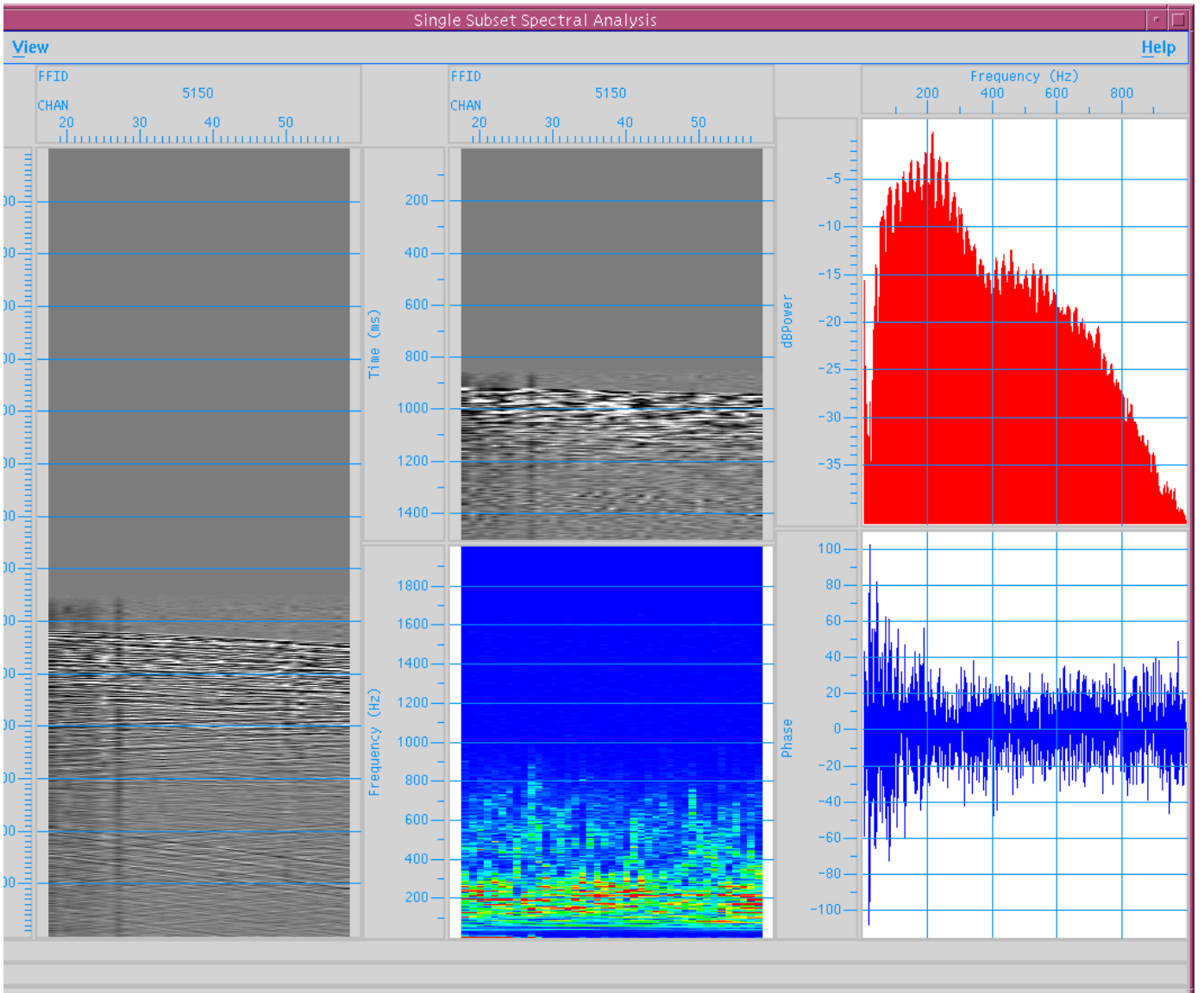
Comparison of shotholes in firn vs. below firn



Twenty meter shothole



Sixty meter shothole



Ice stream D seismic profiles

- DL1: 15km profile straddling the “driving-stress” onset

  Region where ice stream speeds up as driving stress decreases

  Determine basal conditions—water, till, sediments

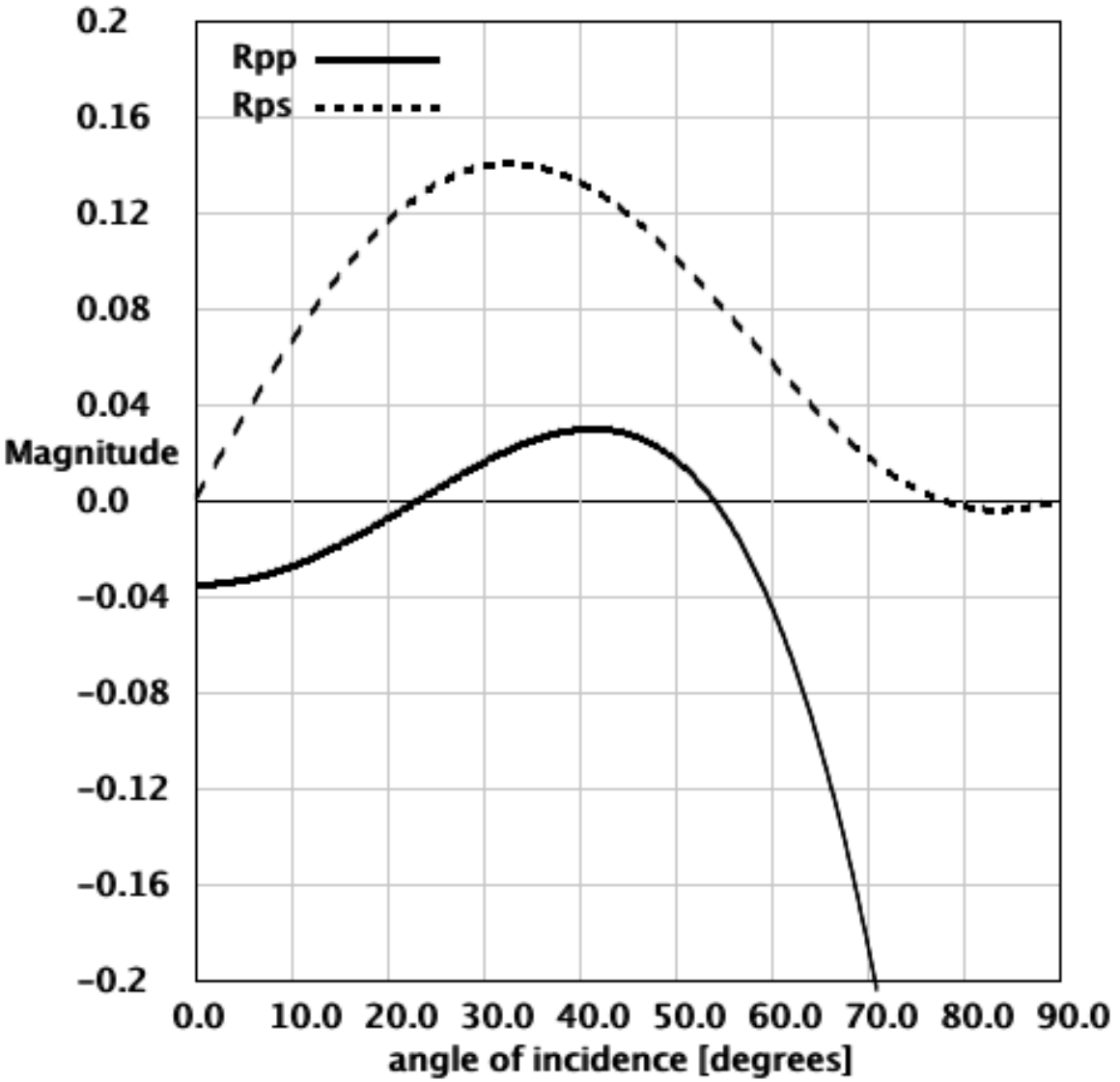
- DT1: 15km cross-stream profile, 30km upstream of DL1

  Region well upstream, examine shear-margin bed conditions

Phase of reflection

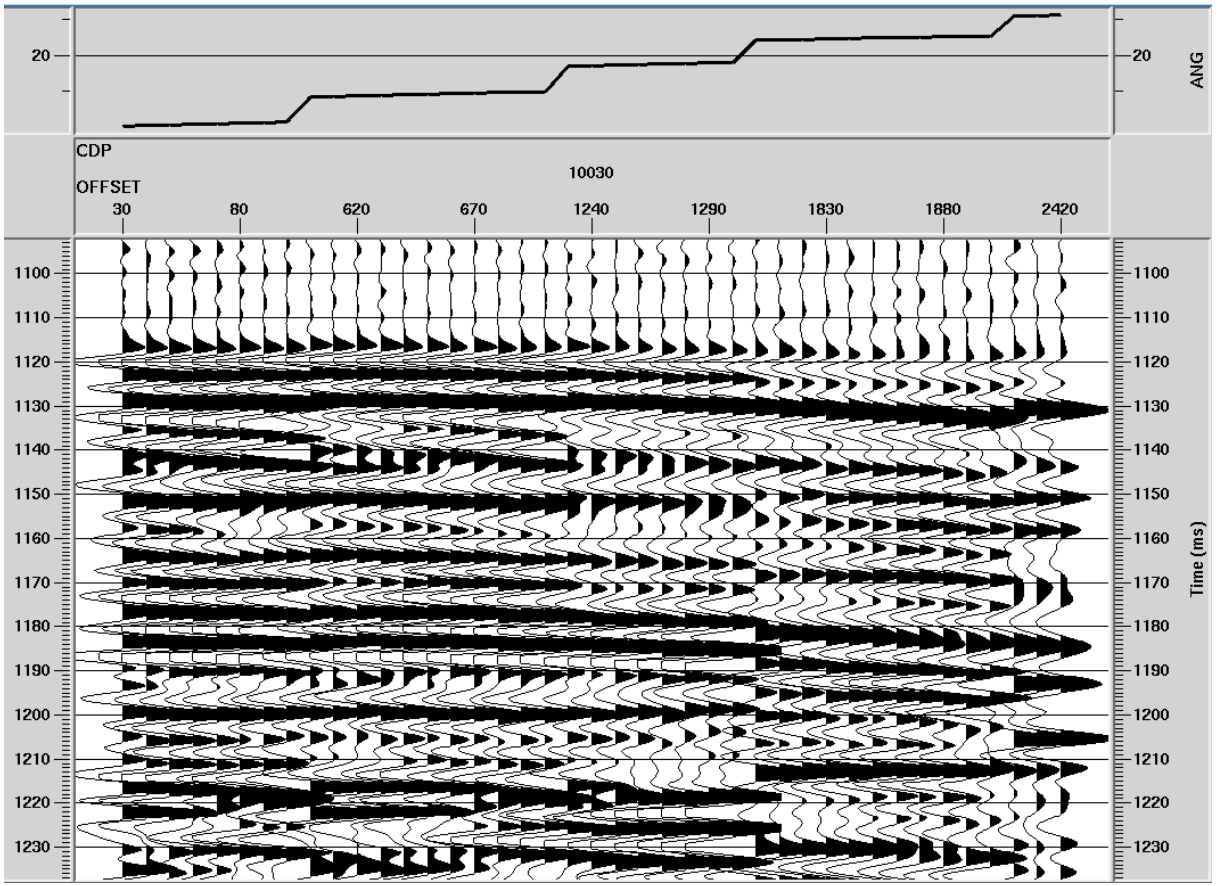
- Normal phase reflection: Layer below the ice is “harder” than ice.
- Reversed phase reflection: Layer below the ice is “softer” than ice.
  - ⋆ Ice is pretty soft...
  - ⋆ Dilatant till is softer, water is softer.
- Layer has to be thick to produce a reflection (meters).

Reflection off $V_p = 1.650$, $V_s = 0.5$



Ice stream D reversed reflection

Reversed phase reflection everywhere beneath isD (DL1, onstream portion of DT1).



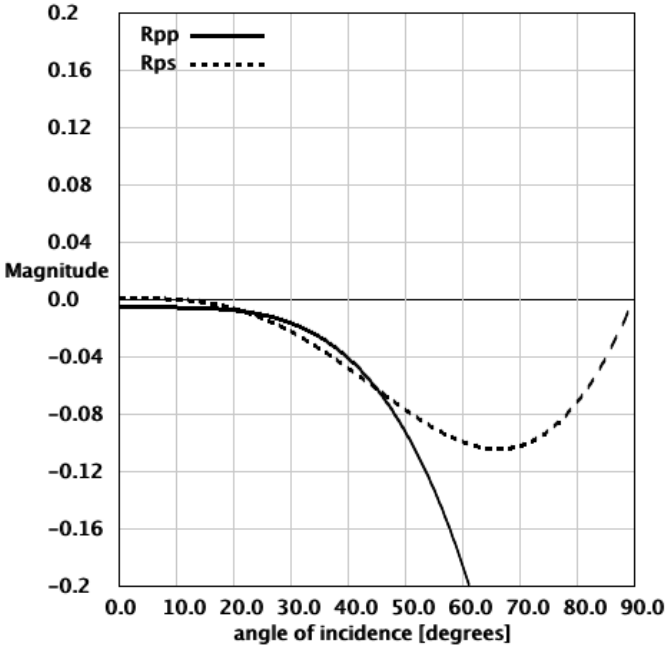
Reflection phase and magnitude (R_{pp} vs. angle i)

- If the vertical reflection is reversed: dilatant till or water.
  - ⋆ Till: $\rho \sim 2$g/cc, $V_p < 1.7$km/s, Poisson: $\nu > 0.4$.
  - ⋆ Water: $\rho = 1, V_p = 1.55, \nu = 0.5$.
  - ⋆ Massive layer: fraction of wavelength ($\lambda/4 =$5–10m).
- Non-vertical reflections (P and S) to further constrain till properties. (work in progress)
- Small-scale roughness from multi-spectral analysis. (work in progress)

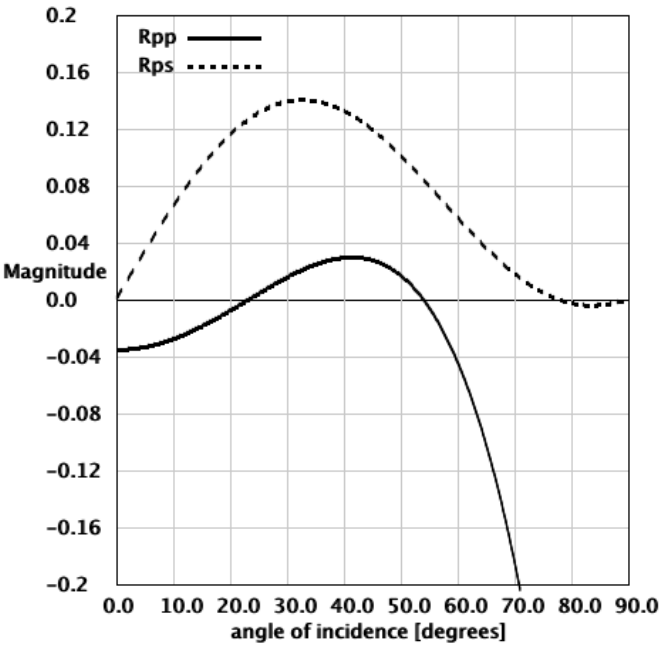
PENNSTATE

Reflectivity

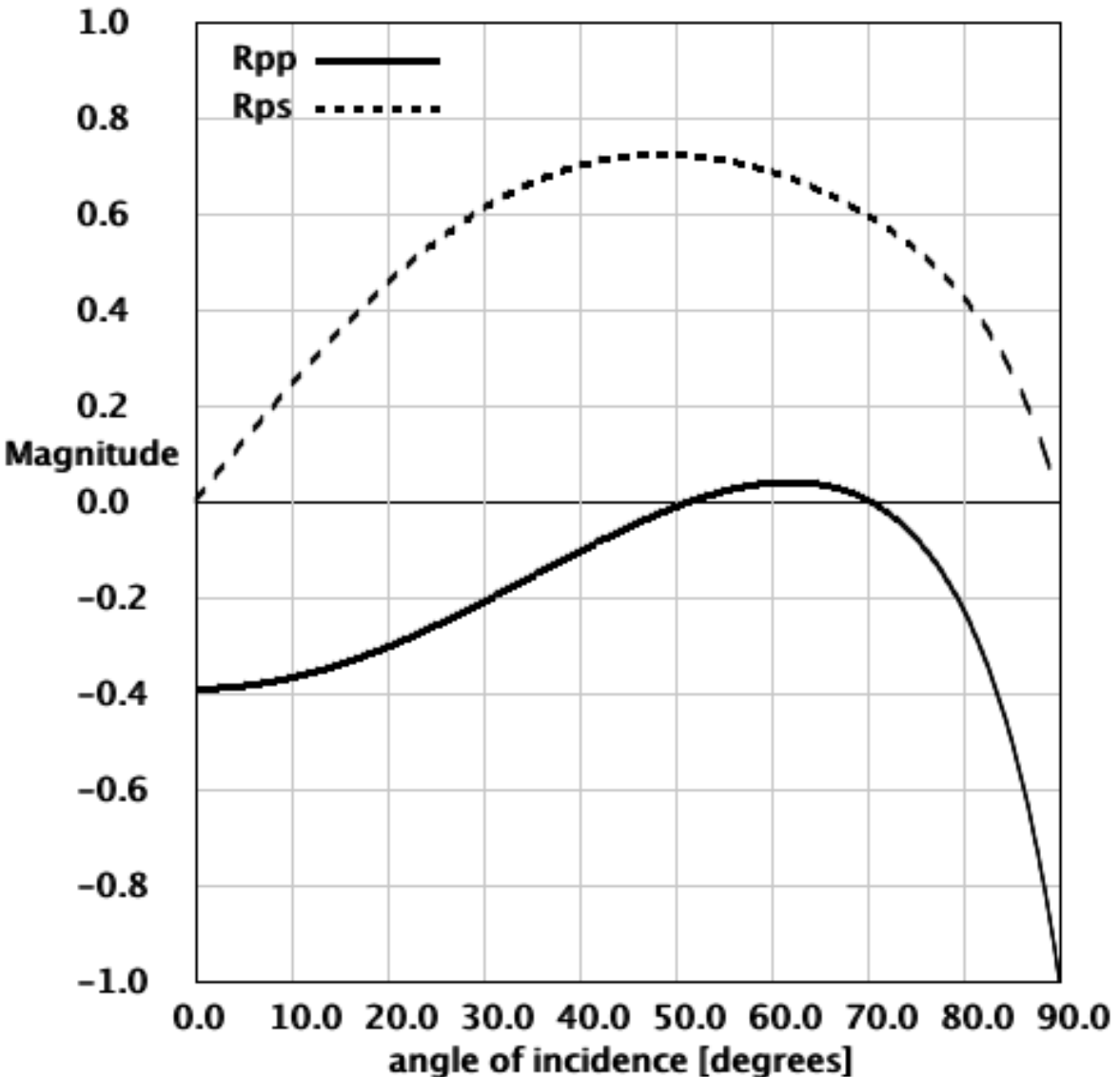
Vp=1750 m/s, Vs=900 m/s



Vp=1650 m/s, Vs=500 m/s

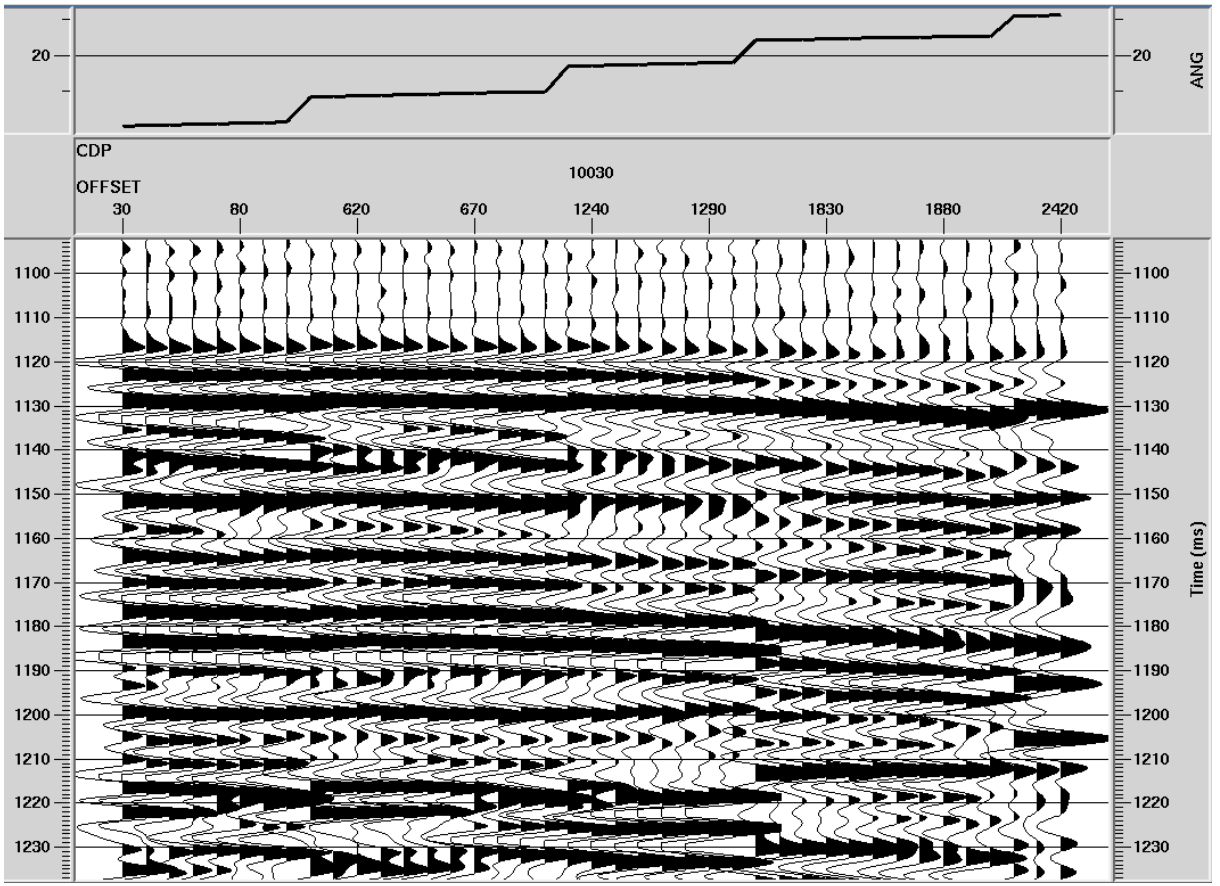


Reflection off water

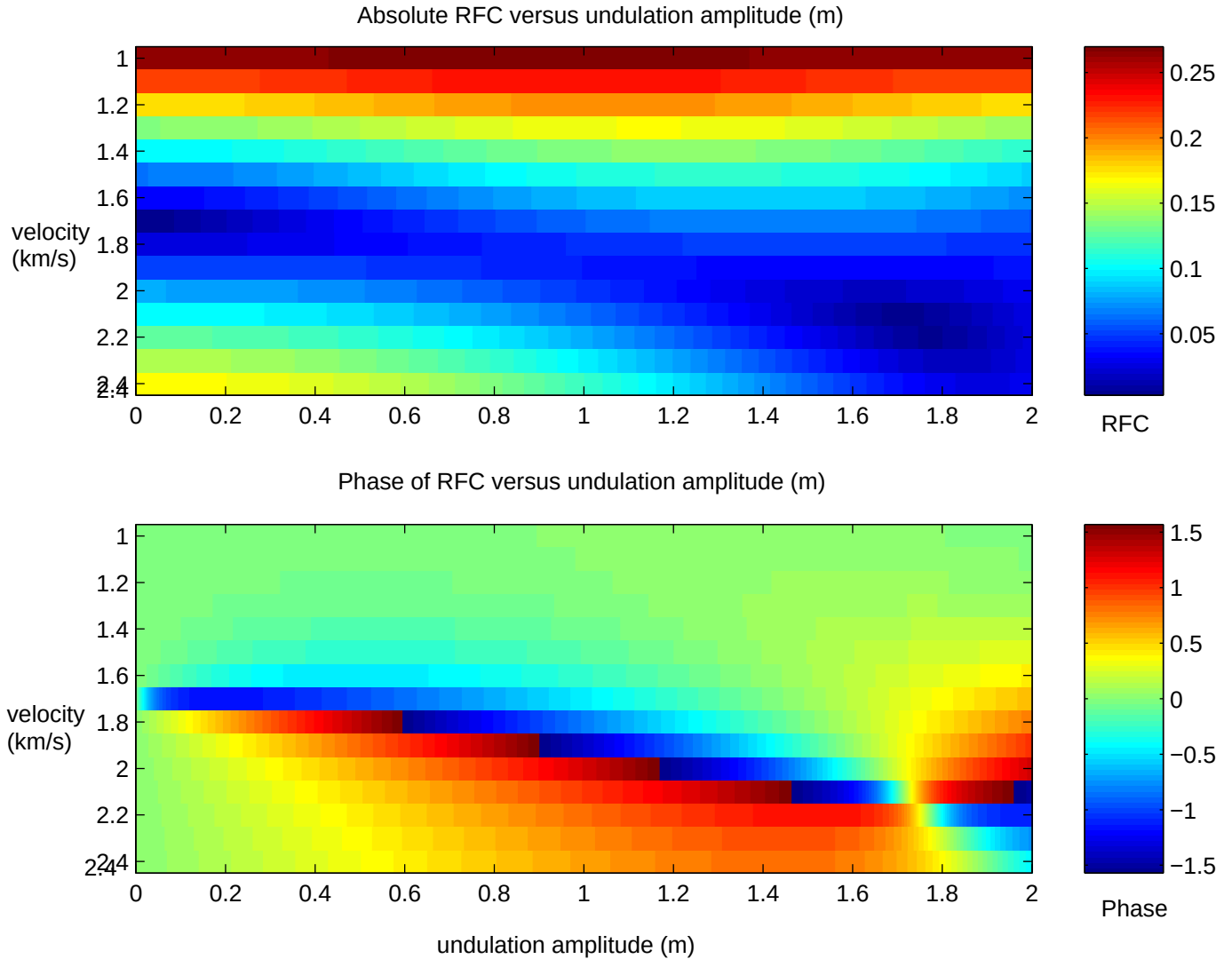


Ice stream D reversed reflection

See the poster for more examples of normal and reversed phase.



Roughness


Absolute RFC versus undulation amplitude (m)
velocity (km/s)
1
1.2
1.4
1.6
1.8
2
2.2
2.4
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0.25
0.2
0.15
0.1
0.05
RFC
Phase of RFC versus undulation amplitude (m)
velocity (km/s)
1.5
1
0.5
0
−0.5
−1
−1.5
Phase
undulation amplitude (m)

Conclusion

- Bed of ice stream D far upstream is extremely soft.

Conclusion

- Bed of ice stream D far upstream is extremely soft.
- Most likely dilatant till. (maybe water, though unlikely)

PENNSTATE

Conclusion

- Bed of ice stream D far upstream is extremely soft.
- Most likely dilatant till. (maybe water, though unlikely)
  - ⋆ Ice streams are efficient at converting sediments to till.

PENNSTATE

Before...

...after.